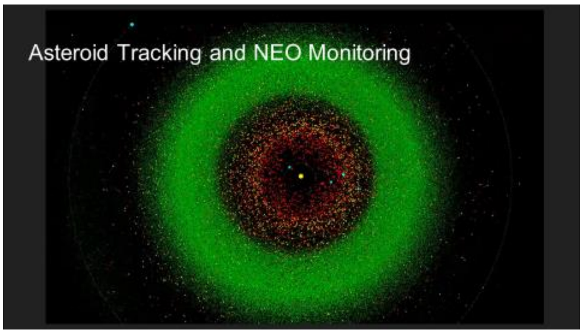
Highly accurate positions of asteroids using astrometry

Alexander G. Carr
Mission design and navigation
Jet Propulsion Laboratory, California Institute of Technology
Pasadena, CA
Alexander1134@hotmail.com

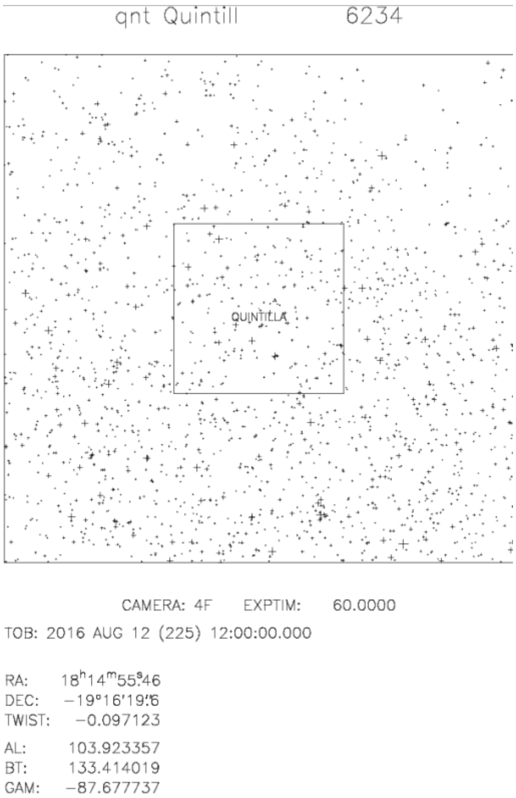
Abstract— Astrometry is the precise measurement of positions in the sky of stars and other celestial bodies. In this paper, measurements of asteroids and outer planet natural satellites are discussed. We used the Astro Mechanics, Ritchey-Chrétien reflecting, 0.6m telescope at Table Mountain Observatory (TMO) located in Wrightwood, CA. Equipped with a 4k CCD camera (the ProLine4096x4096 imaging array with 9µm pixels), using 180 second exposures, we imaged the asteroids and outer satellites. We calculated two to three different positions of the asteroids, with different star fields, to best obtain positions. We obtained many different accurate positions of asteroids and the observing conditions, which were noted, inputted, then reduced with other data. We submit our data to the Minor Planet Center, and by the Solar System Dynamics (SSD) group at JPL. The data are also used for predicting occulting events. Through the execution of several Linux reduction programs and scripts, we reduce the data for the most accurate orbital positions.



PLANNING

We are determining very specific positions, for submission to the Minor Planet Center, and for use of the SSD group at JPL. Many spacecraft have used data from this project to navigate to outer planets and asteroids, including Galileo, Cassini, New Horizons, NEAR Shoemaker, Rosetta, Dawn, and more. But the world's knowledge of asteroid orbits degrades over time because we do not know their exact velocities, so astrometry is an on-going exercise.

We achieve our results by a process which begins with running a Linux prediction script that gives a general position of an asteroid. We decide which asteroids to use based on its Right Ascension (RA) for the time of the year we're observing, and Declination (DEC) values above -34 degrees. The Right Ascension and Declination are like longitude and latitude on Earth, respectively. The RA is measured in hours, minutes and seconds; the DEC is measured in degrees, minutes and seconds. We are also looking for the most reference stars possible in the background. The name and prefix of each asteroid is on the top of each page, along with other information and the date. The date is listed as year, month and date, but is noted by year and numbered day. So, August 12, 2016 would be recorded as 16225, with 16 for 2016 and 225, because August 12 is the 225th day of the year.



We then use overlays to design our photographs, attempting to get the most stars in a square field. We plan for two or three photographs per asteroid, and offset each picture by changing the RA by a few seconds and the DEC by a few minutes. We make the changes and write down the new coordinates. We now have the coordinates of 3 offset pictures to shoot for each asteroid. When there are many stars in the background, we may only take 2 pictures. This planning allows more reference stars to be used in a least-squares fit model, and can help compensate for poor seeing conditions and atmospheric conditions. Uncatalogued stars are also used in the reduction program, for better solutions in the reduction phase. We order the observations in RA throughout the night, and attempt to be as close to hour angle 0 as possible, with the sec z being less than 2.5 (secant z is a calculation of the air mass). We can do this by trying to match our sidereal time with the RA. The HA will tell us how far off the asteroid is from our meridian.

EQUIPMENT AND OBSERVING

We head up the mountain to TMO, and at sunset, we enter a small room adjacent to the Astro Mechanics, Ritchey-Chretien reflecting, 0.6m telescope.

We enter the dome and turn off an air conditioner, which kept the telescope cool throughout the day. We log onto palala, our computer that contains all the clients we will need for the evening. Opening the telescope clients, the camera is connected and then thermoelectric cooling is enabled; we need the camera as cool as possible so no heat can interfere with accurate pixel representation. We open the shutter on the dome with the dome client, wait until it is fully open, and tell the dome to 'follow,' or track, the telescope. The camera needs focusing, so we will open a J2000 catalogue and find a star from the astrometric catalogue located in the position client. We make the readout 8MHz, faster than the 1 MHz, and change the exposure time to 10 seconds instead of the 180 seconds needed for the more accurate asteroid positions. We find a dim star from the catalogue, load the coordinates then 'activate' the slewing of the camera and following of the dome, then we start the exposure. The focus should be sharp, but if we get a 'donut' shape, it is off. We change the focus by commanding changes in the secondary mirror, until it is correct. We then use the 'paddle' client to center the dim star in the picture field. Once this is done, we calibrate the telescope position, return the camera options to 180 seconds and 1MHz output, and we are ready to image the asteroids. We put the new coordinates in the position client, load and activate, and begin the exposure. We immediately write down the time in UTC, the sec z, and the hour angle. For each new asteroid, we note the temperature, barometric pressure and humidity once per asteroid, in a weather file we've created which will be used in the reduction program. We also note the pointing of the exposure, in a pointing file, by RA and DEC, which also will be used in the reduction. Once a night we shoot a calibration field, usually a star cluster, to use in the reduction. We write in our observing log all this information, then we enter the next coordinates for shooting in the position client while waiting for the exposure to finish. As soon as it is downloading, we can load and activate our next positions. We repeat this process with every new asteroid, until the sun rises.

At the end of our night, we will click 'Stop Following' with the dome client, then 'Home Dome.' We will 'Stow' the telescope, and 'Idle' it with TCP; then 'Close dome' with the dome client, once it is home. We then will close all the computer clients, in reverse order, with TCP last. We then fill out the observation log. Next, we bring up WinSCP and connect to dubhe, our reduction computer, and we'll drag the folder containing our pictures from palala to dubhe.

REDUCTION

Several programs and scripts are used on Dubhe in the reduction process to determine highly accurate positions of the asteroids. A master script called 'doit' runs the reduction for each night's data. In this script, several scripts are called up to work different aspects of the data. 'Prepare' script reformats all the picture files, and renames them according to a point file that was created earlier, which has the RA and DEC of each image taken, including exposure duration, date and time, and picture name. 'Amptemp' is where the temperature, barometric pressure and humidity are added, to calculate and solve for atmospheric refracting conditions. The 'Centroid' script does the centerfinding for all the images. This discerns the fainter stars from usable reference stars, and finds the local maxima, while not using ones that don't look like stars, or are too faint for use. Then the 'Reduce' script executes more programs. 'Addhan' figures out the seeing (affected by turbulence in the atmosphere), based on Gaussian sigmas as reported by the centerfinding. The program combines this (root-sum-square) with the uncertainty of the centerfinding process itself to give a somewhat larger net uncertainty in the coordinates (WMO). The calculated seeing affects the uncertainty in each measurement to account for "wiggle" in the atmosphere. The 'Trajectory Geometry Program', or tgp, reads the ephemeris files, so it would know where it is in relation to the earth and the asteroids. This is the major tool for optical navigation, and it shows what a spacecraft would see, though for our uses, the observatory is our "spacecraft." We use tgp for our initial predictions used for calculating how to plot the offsets as well. The 'Astrometric Matching Program' or 'amp,' locates the reference stars and target for each picture. The 'Astrometric Observables and Partials Generator' recalculates the expected position for each image and forms the residual for each image. It calculates the partial derivatives of the expected position with respect to the camera pointing, telescope focal length, telescope distortion parameters, and the RA and DEC of the target. The 'Astrometric Data Analysis Program', or 'adap,' calculates the least-squares fit. This solves for the DEC and RA, the focal length, and distortion parameters. We will get a report with solution values first, sexagesimal and decimal DEC and RA, the changes from initial value, the sigmas, and all the measurement residuals in pixels (WMO). We will have the standard deviation and residual mean from a created table. Adjustment to unit weight will tell us how far off we are from the expected deviation. We are looking for a value of 1, or between 0.6 and 1.6. The script 'Report' when run, will give us a final total of targets, reference stars, uncatalogued stars, the number of images in each of them, and the number of pictures processed. We run 'findbad' to get the number of bad residuals for each of our prefixes. We can correct them by deleting uncatalogued stars or targets through editing the input file for adap. We run xrover, which allows us to find the center of dim asteroids, then we run the ctrpsf script. If the asteroid is too close to a star, we can fix this with a technique called 'pairs,' and get a joint solution. We look for any mistakes in the temp or point files, and if all is well, we can re-run 'reduce' and prepare for delivery. If we get good results with ctrpsf, we are ready to deliver the data. We will re-run findbad, run check, run xrover and ctrpsf, and reduce again for certainty. Then we deliver our data to the Minor Planet Center.

RESULTS

An example of our results are as follows, as published in the Minor Planet Center's circular:

COD 673
CON W. M. Owen Jr., Jet Propulsion Laboratory 301-150, Pasadena CA 91109-8099
CON [wmo@jpl.nasa.gov]
OBS A. G. Carr
OBS J. A. Dial
MEA A. G. Carr
MEA J. A. Dial
MEA W. M. Owen Jr.
TEL 0.61-m f/16 reflector + CCD
NET UCAC5
NUM 88
ACK 17193
00003 C2017 07 12.35856518 31 50.446-05 25 50.10 673
00003 C2017 07 12.36089118 31 50.325-05 25 50.54 673
00006 C2017 07 12.24843817 21 09.138-05 49 48.84 673
00006 C2017 07 12.25084517 21 09.030-05 49 49.84 673
00023 C2017 07 12.49167821 42 04.498-27 10 55.52 673
00023 C2017 07 12.49415521 42 04.400-27 10 56.38 673…

where the numbers 00003, 00006 and 00023 indicate different asteroids, and the exact positions in right ascension and declination are published as observed (OBS) by A.G. Carr and J.A. Dial, and Measured (MEA) by us with our mentor, W.M. Owen Jr. The telescope is the 0.61-m f/16 reflector + CCD. NUM is the number of observations and 673 indicates the Table Mountain Observatory. This a short sample of the total data obtained over three nights, and submitted in MPC format.

CONCLUSION

We deliver the new, more accurate asteroid positions to the Minor Planet Center. These data join hundreds of other scientists' data for the purposes of optical navigation and determining and planning for asteroid occultations. Our work at JPL and Table Mountain Observatory is an on-going, necessary exercise maintaining a highly accurate account of thousands of asteroids and NEO's, as well as planetary satellites.

ACKNOWLEDGEMENTS

This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, and at the Table Mountain Observatory; and was sponsored by the CURE program supported by the National Science Foundation grant # 1460538 to Los Angeles City College; and the National Aeronautics and Space Administration. We would like to give special thanks to:

William M. Owen Jr., JPL; mentor
Paul McCudden, Physics dept., LACC; CURE coordinator
Heath Rhoades, JPL
National Science Foundation & CURE Program

REFERENCES

W. M. Owen, Jr., S. P. Synnott and G. W. Null, Jet Propulsion Laboratory. "High-accuracy asteroid astrometry from Table Mountain Observatory," *Modern Astrometry and Astrodynamics*. R. Dvorak, H. F. Haupt, and K. Wodnar, eds. (Verlag der Österreichischen Akademie der Wissenschaften, Vienna), 1998, pp. 89-102.